

U.S. DEPARTMENT OF COMMERCE PATENT & TRADEMARK OFFICE

B/O Form PTO-1390		Transmittal Letter to the United States Designated/Elected Office (DO/EO/US) Concerning a Filing Under 35 USC 371		Attorney's Docket Number HING3001/REF
International Application Number PCT/GB99/03283		International Filing Date October 3, 1999		U.S. Application Number if known 09/787922
Title of Invention FOAMED CERAMICS		Priority Date Claimed October 5, 1998		
Applicant(s) for DO/EO/US HING et al.				

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items under 35 USC 371:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 USC 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 USC 371.
3. ☒ This express request to begin national examination procedures (35 USC 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 USC 371(b) and PCT Articles 22 and 39(1).
4. ☒ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. ☒ A copy of the International Application as filed 35 USC 371(c)(2).
 - a. ☐ is transmitted herewith (required only if not transmitted by the International Bureau).
 - b. ☒ has been transmitted by the International Bureau.
 - c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☐ A translation of the International Application into English (35 USC 371(c)(2)).
7. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 USC 371(c)(3))
 - a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
 - b. ☐ have been transmitted by the International Bureau.
 - c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
 - d. ☒ have not been made and will not be made.
8. ☐ A translation of the amendments to the claims under PCT Article 19 (35 USC 371(c)(3)).
9. ☐ An oath or declaration of the inventor(s) (35 USC 371(c)(4)). (☐ Executed ☐ Unexecuted)
10. ☐ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 USC 371(c)(5)).

Items 11 to 16 below concern other document(s) or information included:

11. ☒ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
12. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. ☒ A **FIRST** preliminary amendment.
 - ☐ A **SECOND** or **SUBSEQUENT** preliminary amendment.
14. ☐ A substitute specification.
15. ☐ A change of power of attorney and/or address letter.
16. ☒ Other items or information: Small Entity Status is asserted by Applicants for this application.

Application Number (if known) 09/787922		International Application Number PCT/GB99/03283		Attorney's Docket Number HING3001/REF	
				Calculations	PTO USE ONLY
17. The following fees are submitted: Basic National Fee (37 CFR 1.492(a)(1)-(5)): <input checked="" type="checkbox"/> Search report has been prepared by the EPO or JPO \$860.00 <input type="checkbox"/> International Preliminary Examination Fee paid to USPTO (37 CFR 1.482) \$690.00 <input type="checkbox"/> No International Preliminary Examination Fee paid to USPTO (37 CFR 1.482) but International Search Fee paid to USPTO (37 CFR 1.445(a)(2)) \$710.00 <input type="checkbox"/> Neither International Preliminary Examination Fee (37 CFR 1.482) nor International Search Fee (37 CFR 1.445(a)(2)) paid to USPTO \$1000.00 <input type="checkbox"/> International Preliminary Examination Fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(1)-(4) \$100.00				\$860.00	
ENTER APPROPRIATE BASIC FEE AMOUNT				\$ 860.00	
Surcharge of \$130.00 for furnishing the oath or declaration later than <input type="checkbox"/> 20 <input type="checkbox"/> 30 months from the earliest claimed priority date (37 CFR 1.492(e)).					
CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total Claims	31 -20 =	11	× \$18.00	\$ 198.00	
Independent Claims	1 -3 =	0	× \$80.00	\$ 0.00	
Multiple Dependent Claims (if applicable)			+ \$270.00		
TOTAL OF ABOVE CALCULATIONS				\$ 1,058.00	
Reduction by ½ for filing by small entity, if applicable. Small Entity Status is asserted pursuant to 37 CFR 1.27 for this application.				\$ 529.00	
SUBTOTAL				\$ 529.00	
Processing fee of \$130.00 for furnishing the English translation later than <input type="checkbox"/> 20 <input type="checkbox"/> 30 months from the earliest claimed priority date (37 CFR 1.492(f)).					
TOTAL NATIONAL FEE					
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). \$40.00 per property.					
TOTAL FEES ENCLOSED				\$ 529.00	
Amount to be:				Refunded:	
				Charged:	

- a. ☒ A check in the amount of \$529.00 to cover the fees is enclosed.
 b. ☐ Please charge my **Deposit Account Number 02-0200** in the amount of \$_____ to cover the above fees.
 A duplicate copy of this sheet is enclosed.
 c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to **Deposit Account Number 02-0200**. A duplicate copy of this sheet is enclosed.

Note: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

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DATE: April 2, 2001

Respectfully submitted,

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09/787922

532 Rec'd PCT/PTO 02 APR 2001

PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of:

HING et al.

U.S. National Phase of PCT/GB99/03283

Entry papers filed herewith April 2, 2001

For: FOAMED CERAMICS

Attention: PCT OFFICE

PRELIMINARY AMENDMENT
AND INFORMATION DISCLOSURE STATEMENT

Assistant Commissioner for Patents
Washington, D.C. 20231

Sir:

The present application is the U.S. national phase of international application number PCT/GB99/03283. The following amendments pertain to the claims as amended.

Please note that the amended claim pages 22-26 attached to the International Preliminary Examination Report (Annexes) and submitted herewith, have replaced the originally filed pages 22-27 of the application. The claims to be examined and amended by this preliminary amendment are found on amended pages 22-26.

Please amend the above-identified application as follows:

IN THE SPECIFICATION:

Please add the attached ABSTRACT OF THE DISCLOSURE to the application.

IN THE CLAIMS:

Please replace original claims 4-12, 14, 16-17, 19, 21-23, 25-28 and 30-31 with amended claims 4-12, 14, 16-17, 19, 21-23, 25-28 and 30-31 as follows.

4. (Amended) A method as claimed in claim 1, wherein foaming of the ceramic slip is achieved using a ball mill in conjunction with gassing and/or a blowing agent.

5. (Amended) A method as claimed in claim 1, wherein the ceramic slip has a viscosity in the range of from 30 to 100 mPas.

6. (Amended) A method as claimed in claim 1, wherein the ceramic particulate is biocompatible.

7. (Amended) A method as claimed in claim 1, wherein the ceramic particulate comprises one or more of hydroxyapatite, a substituted-hydroxyapatite, a glass, an AW-glass ceramic and/or alumina.

8. (Amended) A method as claimed in claim 1, wherein the ceramic particulate has a d_{50} of from 1 to 300 μm , preferably from 1 to 15 μm .

9. (Amended) A method as claimed in claim 1, wherein the ceramic particulate has a surface area in the range of from 5 to 200 m^2g^{-1} .

10. (Amended) A method as claimed in claim 1, wherein the organic binder comprises one or more of poly (vinyl alcohol), poly (vinyl pyrrolidone), alginate, poly (lactic acid), poly (vinyl butyral), poly (ethylene glycol) and/or poly (vinyl acetate).

11. (Amended) A method as claimed in claim 1, wherein the liquid carrier comprises water, propan-2-ol or trichloroethane.

12. (Amended) A method as claimed in claim 1, wherein the organic binder is present in the liquid carrier in an amount of from 0.2 to 10 w/v%.

14. (Amended) A method as claimed in claim 1, wherein the ceramic slip comprises from 10 to 95 w/v% ceramic particulate.

16. (Amended) A method as claimed in claim 1, wherein the ceramic slip further comprises one or both of a dispersant and/or a defloculant.

17. (Amended) A method as claimed in claim 1, wherein prior to burn-out of the organic binder the liquid carrier is allowed to evaporate from the foamed carrier slip.

19. (Amended) A method as claimed in claim 17 [or claim 18], wherein the concentration of the organic binder in the liquid carrier is selected such that the percentage of binder remaining after substantially all of the liquid carrier has been evaporated is from 0.5 to 10 w/w%.

21. (Amended) A method as claimed in claim 1, wherein the foamed ceramic slip is cast in a mould having a surface coated with a release agent.

22. (Amended) A method as claimed in claim 1, wherein burn-out of the organic binder is carried out at a temperature in the range of from 150 to 700°C.

23. (Amended) A method as claimed in claim 1, further comprising sintering the ceramic foam following burn-out of the organic binder.

25. (Amended) A method as claimed in claim 23, wherein the sintered ceramic foam has a bulk porosity in the range of from 40 to 95%, preferably from 70 to 90%.

26. (Amended) A method as claimed in claim 1, wherein the sintered ceramic foam has a strut density in the range of from 60 to 95%, preferably from 70 to 90% of the theoretical density of the ceramic.

27. (Amended) A method as claimed in claim 23, wherein the sintered ceramic foam has a modal pore size in the range of from 100 to 2000 μm , preferably from 100 to 1000 μm .

28. (Amended) A macroporous ceramic foam obtainable by a method according to claim 1.

30. (Amended) A composition which comprises a macroporous ceramic foam, or a synthetic bone material as claimed in claim 29 together with a pharmaceutically acceptable diluent or carrier.

31. (Amended) A bone implant, filler, cement, tissue engineering scaffold, synthetic bone graft or drug-delivery device which comprises a macroporous ceramic foam, a synthetic bone material or a composition as claimed in claim 30.

REMARKS

Applicants have amended the claims in order to reduce the initial filing fee by deleting the multiple dependent claims from the application. Applicants retain the right to reintroduce any subject matter canceled by the present Amendment at any time during the prosecution of this application or any further application claiming benefit of this application.

Applicants have amended the application to substitute the originally filed pages 22-27 with the amended pages 22-26 attached to the International Preliminary Examiner Report (Annexes) and included in the application as filed herewith. Also, an Abstract of the Disclosure has been added to the application.

Applicants are submitting herewith a copy of the Search Report which issued on International Application No. PCT/GB99/03283, of which the present application is the U.S. national phase. All of the publications cited in the International Search Report are listed on the attached Form PTO-1449. It is Applicants' understanding that, under the procedures of the PCT, copies of the cited publications will have been supplied to the U.S. Patent Office by the International Bureau. However, the Examiner is invited to contact the undersigned attorney if additional copies are necessary or would facilitate examination of the present application.

Otherwise, the Examiner is respectfully requested to return an initialed and dated copy of the attached Form PTO-1449 to confirm that all publications listed thereon have been considered and made officially of record in the file of this application.


Applicants understand that, under the procedures of the PCT, a copy of the priority document (GB 9821663.3, filed 5 October 1998) will have been supplied to the U.S. Patent Office pursuant to Rule 17 of the PCT Regulations. It is therefore

U.S. National Phase of PCT/GB99/03283

respectfully requested that the first Official Action in the present application contain an indication that the appropriate priority document is in the file of this application.

In view of the above amendments, an early action on the application is now in order and is most respectfully requested.

Respectfully submitted,
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REF:kdd
PA01.wpd

DATE: April 2, 2001

Marked-Up Version Showing Changes Made

IN THE CLAIMS:

4. (Amended) A method as claimed in [any one of the preceding claims] claim 1, wherein foaming of the ceramic slip is achieved using a ball mill in conjunction with gassing and/or a blowing agent.

5. (Amended) A method as claimed in [any one of the preceding claims] claim 1, wherein the ceramic slip has a viscosity in the range of from 30 to 100 mPas.

6. (Amended) A method as claimed in [any one of the preceding claims] claim 1, wherein the ceramic particulate is biocompatible.

7. (Amended) A method as claimed in [any one of the preceding claims] claim 1, wherein the ceramic particulate comprises one or more of hydroxyapatite, a substituted-hydroxyapatite, a glass, an AW-glass ceramic and/or alumina.

8. (Amended) A method as claimed in [any one of the preceding claims] claim 1, wherein the ceramic particulate has a d_{50} of from 1 to 300 μm , preferably from 1 to 15 μm .

9. (Amended) A method as claimed in [any one of the preceding claims] claim 1, wherein the ceramic particulate has a surface area in the range of from 5 to 200 m^2g^{-1} .

10. (Amended) A method as claimed in [any one of the preceding claims] claim 1, wherein the organic binder comprises one or more of poly (vinyl alcohol), poly (vinyl

pyrrolidone), alginate, poly (lactic acid), poly (vinyl butyral), poly (ethylene glycol) and/or poly (vinyl acetate).

11. (Amended) A method as claimed in [any one of the preceding claims] claim 1, wherein the liquid carrier comprises water, propan-2-ol or trichloroethane.

12. (Amended) A method as claimed in [any one of the preceding claims] claim 1, wherein the organic binder is present in the liquid carrier in an amount of from 0.2 to 10 w/v%.

14. (Amended) A method as claimed in [any one of the preceding claims] claim 1, wherein the ceramic slip comprises from 10 to 95 w/v% ceramic particulate.

16. (Amended) A method as claimed in [any one of the preceding claims] claim 1, wherein the ceramic slip further comprises one or both of a dispersant and/or a defloculant.

17. (Amended) A method as claimed in [any one of the preceding claims] claim 1, wherein prior to burn-out of the organic binder the liquid carrier is allowed to evaporate [from] from the foamed carrier slip.

19. (Amended) A method as claimed in claim 17 [or claim 18], wherein the concentration of the organic binder in the liquid carrier is selected such that the percentage of binder remaining after substantially all of the liquid carrier has been evaporated is from 0.5 to 10 w/w%.

21. (Amended) A method as claimed in [any one of the preceding claims] claim 1, wherein the foamed ceramic slip is cast in a mould having a surface coated with a release agent.

22. (Amended) A method as claimed in [any one of the preceding claims] claim 1, wherein burn-out of the organic binder is carried out at a temperature in the range of from 150 to 700°C.

23. (Amended) A method as claimed in [any one of the preceding claims] claim 1, further comprising sintering the ceramic foam following burn-out of the organic binder.

25. (Amended) A method as claimed in claim 23 [or claim 24], wherein the sintered ceramic foam has a bulk porosity in the range of from 40 to 95%, preferably from 70 to 90%.

26. (Amended) A method as claimed in [any one of the preceding claims] claim 1, wherein the sintered ceramic foam has a strut density in the range of from 60 to 95%, preferably from 70 to 90% of the theoretical density of the ceramic.

27. (Amended) A method as claimed in [any one of the claims 23 to 26] claim 23, wherein the sintered ceramic foam has a modal pore size in the range of from 100 to 2000 µm, preferably from 100 to 1000 µm.

28. (Amended) A macroporous ceramic foam obtainable by a method according to [any one of the preceding claims] claim 1.

30. (Amended) A composition which comprises a macroporous ceramic foam, [as claimed in claim 28] or a synthetic bone material as claimed in claim 29 together with a pharmaceutically acceptable diluent or carrier.

31. (Amended) A bone implant, filler, cement, tissue engineering scaffold, synthetic bone graft or drug-delivery device which comprises a macroporous ceramic

foam [as claimed in claim 28], a synthetic bone material [as claimed in claim 29] or a composition as claimed in claim 30.

ABSTRACT OF THE DISCLOSURE

The present invention relates to a method for the production of a macroporous ceramic foam, which method comprises: (a) forming a ceramic slip comprising a substantially homogeneous mixture of a ceramic particulate, an organic binder in a liquid carrier, and optionally one or more surfactants, wherein at least one surfactant is present if the organic binder does not function as a surfactant, and wherein the ceramic slip preferably has a viscosity in the range of from 15 to 200 mPas⁻¹; (b) foaming the ceramic slip; and (c) heating the foamed ceramic slip at a temperature sufficient to substantially burn out the organic binder. The macroporous ceramic foam is suitable for use in biomedical applications such as synthetic bones, tissue engineering scaffolds or drugdelivery devices.

Foamed Ceramics

The present invention relates to a method for producing foamed ceramic materials and, in particular, foamed ceramic materials which are suitable for use in biomedical applications.

The replacement of old, damaged or diseased bone is now an established procedure and an estimated 40,000 hip replacements are performed annually within Britain alone, of which 18% are revisions. As surgical technique and medical knowledge continue to advance, there is a growth in the demand for synthetic bone replacement materials, especially with health concerns regarding homologous bone grafts, which are associated with the risks of viral infections, such as Hepatitis B and Human Immune deficiency Virus. Consequently, there is an increasing interest in the development of synthetic bone replacement materials for the filling of both load bearing and non-load bearing osseous defects, such as in joint and facial reconstruction, with a resulting expansion in this field of research.

The biocompatibility of hydroxyapatite (HA), coupled with the similarities between the crystal structure of HA and the mineral content of bone, has led to great interest in HA as a material for the augmentation of osseous defects. The apatite group of minerals are based on calcium phosphate, with stoichiometric hydroxyapatite having a molar ratio of Ca/P of 1.67. HA has the chemical formula $\text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2$. There has also been increasing interest in the development of biomaterials, such as

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bioactive glasses and substituted apatites, which more closely match the chemical composition of bone mineral, resulting in faster bone bonding between implant and host. However, as a result of the poor
5 mechanical properties of all of these materials, clinical usage has been limited to coatings and non-load bearing porous structures or granules.

10 Porous bio-ceramic implants offer the potential of tailored-skeletal repair and reconstruction in a variety of orthopaedic procedures, as well as secure fixation of the implant as a result of bony ingrowth and mechanical interlock. There are a number of
15 porous HA based implant materials currently available on the commercial market, for example Unilab, Surgibone, Endobon (RTM), Ceros, Interpore. Many of these materials are derived from either animal cancellous bone or coral, which is hydrothermally
20 treated so as to convert the natural ceramic component into hydroxyapatite, while preserving the natural porous structure. For example, Endobon (RTM) is produced via the hydrothermal conversion of bovine cancellous bone. Others are formed by conventional
25 burn-out routes, wherein polymer beads dispersed throughout a ceramic structure are burnt out to leave a foam-like structure. This procedure generates significant gaseous by-products and often results in cracking of the structure.

30 There is limited information and control on the physical characteristics, such as the modal macro-pore size or the degree of pore inter-connectivity, in many of these porous structures, and in some cases there is limited control over the chemical composition. Both

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the physical and chemical properties influence the quality and rate of bone ingrowth within these materials on implantation. Furthermore, the mechanical properties are highly sensitive to both density- and anisotropy- parameters, which again are not well controlled in many of the current production routes. Therefore, there is a need for the development of a novel production route which allows control of the physical and chemical properties of the final product. This results in improved implants in terms of mechanical and biological performance, as a function of tailored properties and improved reproducibility.

Ceramic foams are conventionally formed by infiltrating a polymer foam with a slip, which is a fine slurry of ceramic particles in a fluid, such as water. When the aggregate is fired, the slip bonds to the polymer foam to give an image of the original foam, which is burnt off. Ceramic foams may also be made by chemical vapour deposition on to a substrate of reticulated carbon foam.

The present invention aims to provide a method for the manufacture of porous materials with highly interconnected porosity, which are suitable for use in medical applications.

Accordingly, the present invention provides a method for the production of a macroporous ceramic foam, which method comprises:

- (a) forming a ceramic slip comprising a substantially homogeneous mixture of a ceramic particulate, an

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organic binder in a liquid carrier and optionally one or more surfactants, wherein at least one surfactant is present if the organic binder does not function as a surfactant, and wherein the ceramic slip preferably has a viscosity in the range of from 15 to 200 mPas⁻¹;

- (b) foaming the ceramic slip; and
- (c) heating the foamed ceramic slip at a temperature sufficient to substantially burn out the organic binder.

For the avoidance of doubt, by the term macroporous, as applied to an open foam structure, is meant a ceramic foam containing pores with a modal diameter $d_{\text{mode}} \geq \approx 100 \mu\text{m}$. By the term microporous, as applied to the porosity within the struts of the ceramic foam, is meant containing pores with a modal diameter $0.1 \mu\text{m} \leq d_{\text{mode}} \leq 50 \mu\text{m}$.

Foams are three-dimensional cellular solids and may be classified as either open-celled or closed-cell. The relative density of a cellular material is defined as the ratio of the density of the cellular material to that of the solid material. For bone, the relative density generally falls within the range of from 0.05 to 0.7, i.e. 30 to 95 % porous. Furthermore, determination of the relative density of a porous structure can give an indication of the degree of pore connectivity with the structure. For cancellous bone, a structure with a relative density of less than approximately 0.2 (i.e. 80 % porous) is generally classed as open, while one with a relative density of

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more than approximately 0.2 (i.e. 80% porous) will possess a closed (non-interconnected) porosity.

5 The ceramic slip preferably has a viscosity in the range of from 15 to 200 mPas⁻¹, more preferably from 30 to 100 mPas⁻¹. It has been found that the viscosity of the slip is important for producing a stable foam, prior to burning out the binder. The presence of a surfactant in the slip also assists in
10 producing a stable foam. It will be appreciated that if the binder is capable itself of acting to a sufficient extent as a surfactant, then the optional surfactant(s) may be dispensed with. Suitable examples of surfactants for use in the present
15 invention include Saponin and Decon 90.

The ceramic particulate may be a biocompatible ceramic and may comprise, for example, one or more of hydroxyapatite, a substituted-hydroxyapatite and/or
20 alumina, or any other ceramic used in biomedical applications. The ceramic particulate may also comprise a glass or a glass-ceramic such as, for example, an AW-Glass ceramic. The ceramic particulate may preferably be either a spray dried and/or calcined
25 powder, or, advantageously, it may be directly obtained from the as-precipitated filter cake.

In general, the ceramic particulate has a particle size distribution with the following
30 characteristics: d_{10} from 0.5 to 20, preferably from 0.5 to 5 μm , more preferably from 1 to 15 μm , still more preferably from 0.7 to 2.5 μm , still more preferably from 0.9 to 2.1 μm ; d_{50} from 1 to 300 μm , preferably from 2 to 150 μm , more preferably from 1 to

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15 μm , still more preferably from 1 to 10 μm , still more preferably from 3 to 8 μm ; and a d_{50} of from 5 to 150 μm , preferably from 5 to 50 μm , more preferably from 10 to 50 μm , still more preferably from 10 to 40 μm , still more preferably from 10 to 25 μm . The mode of the particle size will typically fall in the range of from 1 to 400 μm , preferably from 2 to 250 μm , more preferably from 1 to 10 μm , still more preferably from 3 to 6 μm . The ceramic particulate typically has a surface area of from 5 to 200 m^2g^{-1} , preferably from 7 to 100 m^2g^{-1} , more preferably from 7 to 20 m^2g^{-1} , and still more preferably from 7 to 14 m^2g^{-1} . Particle sizes were measured using a Malvern Mastersizer. Surface areas were measured using a Micromeritics B.E.T. Surface Analyser.

The organic binder serves to provide plasticity during forming of the ceramic particulate and green strength in the formed product. In the present invention, the organic binder preferably comprises an organic binder, which is preferably water soluble. Suitable examples include vinyl polymers, such as poly(vinyl alcohol), poly(vinyl pyrrolidone), poly(vinyl acetate) and/or poly(vinyl butyral). Other suitable examples include alginate, poly(lactic acid) and poly(ethylene glycol). It will, however, be appreciated that any polymeric species capable of providing mechanical stability to a pre-sintered ceramic foam body may be used. It will also be appreciated that the organic binders may be used singularly or in a combination of two or more thereof.

The liquid carrier should be one which can substantially dissolve the organic binder and which

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can also be combined with the ceramic powder without causing degradation thereof. Suitable examples include water, preferably double distilled water, alcohols, such as propan-2-ol, and hydrocarbons, such as trichloroethane. The organic binder will generally be present in the liquid carrier in an amount of from 0.2 to 10 w/v%, preferably from 0.2 to 8 w/v%, more preferably from 0.5 to 6 w/v%, still more preferably from 0.5 to 4 w/v%, still more preferably from 1.5 to 3 w/v%.

The ceramic slip preferably comprises in the range of from 10 to 95 w/v% ceramic particulate in the binder and liquid carrier, more preferably from 20 to 90 w/v% ceramic particulate in the binder and liquid carrier, still more preferably from 40 to 80 w/v% ceramic particulate in the binder and liquid carrier. The slip may suitably be prepared by combining the constituents into a homogenous mixture. The concentration of the binder solution added should preferably be selected to ensure that the percentage of binder remaining in a dry casting is in the range of from 0.5 to 10 w/w%, preferably from 1 to 6 w/w%, more preferably from 1 to 4 w/w%. The final slip should preferably have a viscosity in the range of from 15 to 200 mPas⁻¹, more preferably from 30 to 100 mPas⁻¹, and this may be achieved by adjusting the slip viscosity by the addition of extra solvent, as necessary.

The ceramic slip may further comprise one or both of a dispersant and/or a defloculant. Suitable examples include sodium polyacrylate and/or sodium hexameta phosphate.

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Foaming of the ceramic slip may be achieved by one or more of mechanical agitation, gassing and/or the use of a blowing agent, such as H_2O_2 . For example, foaming may be achieved by the use of a mechanical whisk and/or passing a gaseous phase through the slip until a substantially stable homogenous foam has been produced. Advantageously, foaming is achieved by the use of a ball mill (mill-foaming). Suitable milling media includes alumina (Al_2O_3), enstatite ($MgSiO_3$) or zirconia (ZrO_2) balls, preferably having a diameter in the range of from 10 to 30 mm, more preferably from 15 to 25 mm. For biomedical applications, the milling media should be chosen carefully so as to avoid contamination of the slip. The ball mill may be used in conjunction with gassing and/or a blowing agent. The amount of milling media to be used when mill-foaming a ceramic slip is advantageously in the range of from 3 to 20 w/w% ceramic particulate to milling media, more preferably from 5 to 15 w/w%.

There are a number of advantages associated with ball milling foam-stabilised slips, including:-

(i) No organic sponge/foam template or solid pore-formers to burnout; porous ceramics produced by burnout methods often have relatively low mechanical properties resulting from defects in the structure due to incomplete/irregular burnout of the original template.

(ii) Homogeneous or functionally graduated pore distributions are attainable by varying the slip viscosity.

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(iii) Macro-pore size is variable by varying the start-powder particle size.

(iv) Macro-porosity is highly interconnected.

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(v) Microstructure contains an interconnected network of micro-pores, the degree of connectivity of which can be controlled during sintering. This is important for tailoring the drug delivery characteristics of the porous structure.

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Prior to burn-out of the organic binder, the liquid carrier is preferably allowed to evaporate from the foamed ceramic slip. This is beneficial because excessive quantities of the liquid carrier can lead to cracking during the subsequent heat-treatment steps. Evaporation may be facilitated by heating the foamed ceramic slip to a temperature in the range of from 20 to 100°C, preferably 30 to 50°C, and preferably with a flow of air thereover. As already mentioned, the concentration of the organic binder in the liquid carrier is advantageously selected so that the percentage of binder remaining after substantially all of the liquid carrier has been evaporated is in the range of from 0.5 to 10 w/w%, preferably from 1 to 6 w/w%, more preferably from 1 to 4 w/w%, since this has been found to reduce the occurrence of cracking during the subsequent heat-treatment steps. The viscosity of the slip and the presence of a surfactant/stabilizer assist in maintaining the foam structure of the ceramic slip during evaporation of the liquid carrier. In other words, the collapse of the form structure is delayed.

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The foamed ceramic slip will generally be cast in a mould prior to burn-out of the organic binder. The mould preferably has a surface coated with a release agent to ensure release of the casting(s) after removal of the liquid carrier has occurred. The foamed ceramic slip may also be cast (unconstrained) on a flat surface, preferably dusted with a fine ceramic powder. Injection of the foamed ceramic slip into a porous mould is also possible.

It will be appreciated that the burn-out temperature will depend upon the nature of the organic binder. Generally the burn-out temperature will fall in the range of from 150 to 700°C, preferably 300 to 700°C, more preferably 300 to 600°C. Burn-out should preferably be carried out slowly in order to avoid creation of pressures due to decomposition of the organic binder and evaporation of any residual moisture. Sufficient amounts of oxygen or air should preferably be supplied so that substantially complete binder burn-out can occur, and binder burn-out is therefore advantageously carried out in a ventilated furnace. Heating of the foamed ceramic slip is carried out at a rate and temperature sufficient to substantially burn-out the organic binder.

Following burn-out of the organic binder, the ceramic foam may be sintered, again advantageously in a ventilated furnace. The sintering temperature depends upon the nature of the ceramic particulate and will typically fall in the range of from 500 to 1600°C. It will be appreciated that the sintering temperature and atmosphere must be chosen carefully to avoid decomposition of the ceramic material. After

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burn-out, humid, CO₂-rich atmospheres may be required for some ceramics, for example carbonate-substituted apatites. In particular, for carbonate-substituted apatite foams, specimens are preferably sintered at a temperature in the range of from 600 to 1000°C under a carbon dioxide atmosphere, preferably in a tube furnace or the like, which is constantly flushed with CO₂ gas at a flow rate of typically up to 4 lmin⁻¹, preferably from 1 to 3 lmin⁻¹, more preferably approximately 2.0 lmin⁻¹.

In a preferred embodiment of the present invention, following evaporation of the liquid carrier, the substantially dry green castings may undergo a stepped heat-treatment for binder burn-out and densification by sintering. The optimum parameters for the burn-out step will depend on the binder being used. However, castings are typically heated at a rate of from 0.5 to 10°C min⁻¹ (preferably from 1 to 5°C min⁻¹) and held at a burn-out temperature of from 150 to 700°C (preferably from 300 to 700°C) for from 2 to 8 hours. During the burn-out stage it is recommended that air is passed through the furnace at a flow rate of preferably from 0.5 to 2 lmin⁻¹, more preferably from 1 to 2 lmin⁻¹, to ensure substantial removal of the binder. Once burn-out of the binder is complete, castings may be heated directly from the burn-out temperature, at a rate typically from 1 to 20°Cmin⁻¹, to a sintering temperature appropriate for the ceramic powder, typically from 500 to 1600°C. Alternatively, castings that have undergone burn-out may be cooled to room temperature and then sintered. Upon sintering, it has been found that the struts of the material may

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typically densify to from approximately 60 to $\geq 95\%$
(more typically from 70 to $\geq 90\%$) of the theoretical
density. On cooling, the sintered bodies are removed
from the furnace and may be sectioned using a diamond
5 tipped cutting apparatus into the desired geometry.
The resulting solid foamed ceramic material may be
provided in the form of, for example, blocks,
cylinders and granules.

10 The foamed ceramic material produced by the
method according to the present invention may be used
as a synthetic bone material, including dental
materials, for example for use in bone reconstruction
and augmentation, implants, and compaction graft-type
15 fillers and for making hydroxyapatite-polymer
composites.

The final macro-structure of the sintered ceramic
foams produced according to the method of the present
20 invention may be controlled by varying the relative
proportions of the ingredients within the ceramic
slip, the physical characteristics of the ceramic
particulate and the amount of milling media added
during mill-foaming, within the limits specified.
25 Hence, the bulk porosities of ceramic foams produced
via this method typically range from 40 to 95 % (more
typically from 60 to 90 %, still more typically from
60 to 80 %, still more typically from 70 to 80%). The
macro-porosity of the sintered ceramic foams produced
30 according to the method of the present invention are
highly interconnected (as can be seen in Figures 1 to
3). Furthermore, modal macro-pore size varies with
bulk porosity, and ranges from 100 to 2000 μm , more
typically from 100 to 1000 μm (as can be seen in

Figures 7 and 8).

The final micro-structure of the sintered ceramic foams produced according to the method of the present invention may be controlled by varying the relative proportions of the ingredients within the ceramic slip, the physical characteristics of the ceramic particulate, the amount of milling media added during mill-foaming and, additionally by the sintering procedure, within the limits specified. The strut density (or real density) typically ranges from 60 to 95 % (more typically from 70 to 95%, still more typically from 85 to 92 %) of the theoretical density of the ceramic (the theoretical density of hydroxyapatite is 3.156 gcm^{-3}). However, the micro-porosity of the sintered ceramic foams produced according to the method of the present invention are highly interconnected (as can be seen in Figures 4 to 6 and 9 and 10) a characteristic of particular significance for bio-medical application. Furthermore, the degree of interconnectivity within the microstructure of the sintered ceramic foams produced according to the method of the present invention, may be controlled by varying the relative proportions of the ingredients within the ceramic slip, the physical characteristics of the ceramic particulate, the amount of milling media added during mill-foaming and, additionally by the sintering procedure.

$$\text{Real (or Strut) Density} = \frac{\text{Mineralised Mass}}{\text{Volume of Bone Struts}}$$

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$$\text{Apparent (or Bulk) Density} = \frac{\text{Mineralised Mass}}{\text{Total (pore+strut) Volume}}$$

5 $\text{Bulk Porosity (\%)} = 100 \times \left(1 - \frac{\text{Apparent Density}}{\text{Theoretical Density}} \right)$

10 $\text{Apparent Density} = \frac{\text{Dry Weight} \times \text{Density of Water}}{(\text{Saturated weight} - \text{Submerged weight})}$

15 $\text{Real Density} = \frac{\text{Dry Weight} \times \text{Density of Water}}{(\text{Dry weight} - \text{Submerged weight})}$

The present invention will now be described further with reference to the following Examples and Figures, provided by way of example, in which:

20 Figure 1 is a SEM micrograph of a sintered mill-foamed porous ceramic material according to Example 1 of the present invention (sintering temperature 1200°C, magnification x50)

25 Figure 2 is a SEM micrograph of a sintered mill-foamed porous ceramic material according to Example 1 of the present invention (sintering temperature 1300°C, magnification x50)

30 Figure 3 is a SEM micrograph of a sintered mill-foamed porous ceramic material according to Example 1 of the present invention (sintering temperature 1400°C, magnification x1000)

35 Figure 4 is a SEM micrograph of a sintered mill-foamed porous ceramic material according to

Example 1 of the present invention (sintering temperature 1200°C, magnification x1000) (Ref: TAG 396).

5 Figure 5 is a SEM micrograph of a sintered mill-foamed porous ceramic material according to Example 1 of the present invention (sintering temperature 1300°C, magnification x1000)

10 Figure 6 is a SEM micrograph of a sintered mill-foamed porous ceramic material according to Example 1 of the present invention (sintering temperature 1400°C, magnification x50)

15 Figure 7 is a SEM micrograph of a sintered mill-foamed porous ceramic material according to Example 4 of the present invention (55 w/v% particulate to carrier, magnification x50)

20 Figure 8 is a SEM micrograph of a sintered mill-foamed porous ceramic material according to Example 4 of the present invention (50 w/v% particulate to carrier, magnification x50)

25 Figure 9 is a SEM micrograph of a sintered mill-foamed porous ceramic material according to Example 4 of the present invention (55 w/v% particulate to carrier, magnification x1000)

30 Figure 10 is a SEM micrograph of a sintered mill-foamed porous ceramic material according to Example 4 of the present invention (50 w/v% particulate to carrier, magnification x1000)

Figure 11 is a plot of bulk and strut densities of sintered mill-foamed porous ceramics prepared according to Example 1 of the present invention

5 Example 1

3.0 g of polyvinyl alcohol (molecular weight 115000) was dissolved in 170 ml of double distilled water at 40°C, under conditions of continuous stirring. This binder solution was then combined with 100 g of hydroxyapatite powder with a particle d_{50} of 3.3 μm and a surface area of 13.4 m^2g^{-1} . The resulting slip was then placed in a 1 litre mill pot with 945 g of milling media (18 mm diameter alumina balls) and milled at a speed of 120 rpm for 2 hours. The thus foamed slip was then cast on to a flat surface which had been dusted with a fine hydroxyapatite powder, equivalent to 0.1 gcm^{-2} mould area, to ensure release of the casting once dry. Castings were dried in air at a temperature of 40°C for from 12 to 24 hours. The dried green castings underwent a stepped heat treatment in a ventilated furnace for binder burn-out and densification by sintering. Castings were heated at a rate of 2.5°Cmin⁻¹ to 500°C, and held at this temperature for 4 hours. Upon burn-out the castings were then heated at a rate of 2.5°Cmin⁻¹ to temperatures of 1200, 1300 and 1400°C, with no air flow and held for 2 hours. Figures 1 to 6 are SEM micrographs of the thus formed materials: Figure 1 (sintering temperature 1200°C, magnification x50), Figure 2 (sintering temperature 1300°C, magnification x50), Figure 3 (sintering temperature 1400°C, magnification x1000), Figure 4 (sintering temperature 1200°C, magnification x1000), Figure 5 (sintering

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temperature 1300°C, magnification x1000), Figure 6 (sintering temperature 1400°C, magnification x50). The physical characteristics of the sintered specimens are detailed in Figure 11. The theoretical density of hydroxyapatite is 3.156 gcm⁻³.

The results demonstrate how variation of sintering temperature results in control of both the bulk and strut density. Bulk density increases steadily as sintering temperatures increases from 1200 to 1400°C, which reflects shrinkage of the macro-porosity, with a concurrent decrease in the macro-porous connectivity. However, strut density decreases from 1200 to 1400°C as a result of a reduction in micro-pore connectivity leading to an increase in closed micropores.

Example 2

Two slips were prepared as in Example 1. The slips were then each placed in a separate 1 litre mill pot with 630 and 945 g of milling media (18 mm diameter alumina balls) and milled at a speed of 120 rpm for 5 hours. The foamed slips were then cast on to a flat surface which had been dusted with a fine hydroxyapatite powder, equivalent to 0.1 gcm⁻² mould area, to ensure release of the casting once dry. Castings were dried at a temperature of 40°C. The dried green castings underwent a stepped heat treatment for binder burn-out and densification by sintering. Castings were heated at a rate of 2.5°Cmin⁻¹ to 500°C, and held at this temperature for 4 hours. Upon burn-out the castings were then heated at 2.5°Cmin⁻¹ to a temperature of 1300°C, and held for 2

hours. The physical characteristics of the sintered specimens are detailed in Table 1.

Table 1

Weight of Milling Media (g)	Bulk Density (gcm^{-3})	Strut Density (gcm^{-3})
630	0.65	2.75
945	0.54	2.74

The results in Table 1 demonstrate how variation in the weight of the milling media can be used to control of the bulk density (macro-porosity) independently of the strut density. Sintered mill-foamed porous ceramic prepared with a greater loading of milling media have a more open macro-porous structure.

Example 3

3.0 g of polyvinyl alcohol (molecular weight 115000) was dissolved in 130 ml of double distilled water at 40°C, under conditions of continuous stirring. This binder solution was then combined with 100 g of hydroxyapatite powder with a particle d_{50} of 7.5 μm and a surface area of 7.61 m^2g^{-1} . The resulting slip was then placed in a 1 litre mill pot with 945 g of milling media (18 mm diameter alumina balls) and milled at a speed of 120 rpm for 5 hours. The foamed slip was then cast on to a flat surface which had been dusted with a fine hydroxyapatite powder, equivalent to 0.1 gcm^{-2} mould area, to ensure release of the casting once dry. Casting were dried at a temperature

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of 40°C. The dried green castings underwent a stepped heat treatment for binder burn-out and densification by sintering. Casting were heated at a rate of 2.5°C min⁻¹ to 500°C, and held at this temperature for 4 hours. Upon burn-out, the castings were then heated at 2.5°C min⁻¹ to a temperature of 1300°C and held at this temperature for 2 hours. The physical characteristics of the sintered specimens are detailed in Table 2.

Table 2

Bulk Density (gcm ⁻³)	Strut Density (gcm ⁻³)
0.35	2.42

The results in Table 1, compared with the results of the sintered mill-foamed porous ceramics prepared with 945 g milling media in Table 2, demonstrate how variation in the particle size of the ceramic particulate may be used to control the bulk density (macro-porosity) and the strut density (micro-porosity). The sintered mill-foamed porous ceramics prepared with the ceramic particulate possessing a larger particle size had a greater modal pore size of 800 µm as compared to 300 µm.

Example 4

2.0 g of polyvinyl alcohol (molecular weight 115000) was dissolved in 90 ml of double distilled water at 40°C, under conditions of continuous stirring. 2.0 g of polyvinyl alcohol (molecular weight 115000) was dissolved in 100 ml of double

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distilled water at 40°C, under conditions of continuous stirring. These binder solutions were then each combined with 50 g of powdered hydroxyapatite filter-cake with a particle d_{50} of 40 μm and a surface area of 78 $\text{m}^2.\text{g}^{-1}$. The resulting slips were then each placed in a 1 litre mill pot with 450 g of milling media and milled at a speed of 120 rpm for 2 hours. The foamed slips were then cast on to a flat surface which had been dusted with sufficient fine hydroxyapatite powder, equivalent to 0.1 g per cm^2 mould area, to ensure release of the casting once dry. Castings were dried at a temperature of 40°C. The dried green castings underwent a stepped heat treatment for binder burn-out and densification by sintering. Castings were heated at a rate of 1.0 $^{\circ}\text{C}.\text{min}^{-1}$ to 500°C, and held at temperature for 4 hours. Upon burnout the castings were then heated to a temperature of 1250 $^{\circ}\text{C}$, and held at temperature for 2 hours. The physical characteristics of the sintered specimens are illustrated in Figures 7 to 10 and are detailed in Table 3.

Table 3

Liquid	Bulk	Strut
Carrier	Density	Density
(ml)	($\text{g}.\text{cm}^{-3}$)	($\text{g}.\text{cm}^{-3}$)
90	0.84	2.77
100	0.41	2.39

The results in Table 3 and Figures 7 to 10 demonstrate how variation in the ratio of ceramic particulate to binder solution results in variation in both the bulk density (macro-porosity) and the strut

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density (micro-porosity). The sintered mill-foamed porous ceramics prepared with the greater volume of liquid carrier have lower bulk and strut densities reflecting a more open, inter-connected pore structure with larger macro-pores and a larger fraction of micro-porosity. Furthermore, the use of powdered filter-cake has resulted in a more organised network of inter-connected microporosity.

10 The macroporous ceramic foams according to the present invention have the following advantages over the prior art cancellous and coral derived materials. First, the synthetic source means that there is total control over the choice of phase composition and the level of chemical purity. Second, the processing route enables substantially complete control of the pore structure so as to minimise batch variation. Third, substantially isotropic structures can be produced. Fourth, the processing route enables the structural features (such as the pore size and connectivity) of both the macro-porosity and micro-porosity to be tailored to the specific application so that structural and mechanical properties may be matched to particular requirements.

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CLAIMS:

1. A method of producing a macroporous ceramic foam for use in biomedical applications and having an open foam structure containing pores with a modal diameter $d_{mode} \geq 100 \mu m$, which method comprises:

- (a) forming a ceramic slip comprising a substantially homogeneous mixture of a ceramic particulate, an organic binder in a liquid carrier, and optionally one or more surfactants, wherein at least one surfactant is present if the organic binder does not function as a surfactant, and wherein the ceramic slip preferably has a viscosity in the range of from 15 to 200 mPas;
- (b) foaming the ceramic slip using a ball mill; and
- (c) heating the foamed ceramic slip at a temperature sufficient to substantially burn out the organic binder.

2. A method as claimed in claim 1, wherein foaming of the ceramic slip is achieved using a ball mill with milling media selected from alumina (Al_2O_3), enstatite ($MgSiO_3$) or zirconia (ZrO_2) balls.

3. A method as claimed in claim 2, wherein the balls of the milling media have a diameter in the range of from 10 to 30 mm, preferably from 15 to 25 mm.

4. A method as claimed in any one of the preceding claims, wherein foaming of the ceramic slip is achieved using a ball mill in conjunction with gassing.

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and/or a blowing agent.

5. A method as claimed in any one of the preceding claims, wherein the ceramic slip has a viscosity in
5 the range of from 30 to 100 mPas.

6. A method as claimed in any one of the preceding claims, wherein the ceramic particulate is biocompatible.
10

7. A method as claimed in any one of the preceding claims, wherein the ceramic particulate comprises one or more of hydroxyapatite, a substituted-
hydroxyapatite, a glass, an AW-Glass ceramic and/or
15 alumina.

8. A method as claimed in any one of the preceding claims, wherein the ceramic particulate has a d_{50} of
from 1 to 300 μm , preferably from 1 to 15 μm .
20

9. A method as claimed in any one of the preceding claims, wherein the ceramic particulate has a surface area in the range of from 5 to 200 m^2g^{-1} .

10. A method as claimed in any one of the preceding claims, wherein the organic binder comprises one or more of poly(vinyl alcohol), poly(vinyl pyrrolidone), alginate, poly(lactic acid), poly(vinyl butyral), poly(ethylene glycol) and/or poly(vinyl acetate).
25

11. A method as claimed in any one of the preceding claims, wherein the liquid carrier comprises water, propan-2-ol or trichloroethane.
30

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12. A method as claimed in any one of the preceding claims, wherein the organic binder is present in the liquid carrier in an amount of from 0.2 to 10 w/v%.
- 5 13. A method as claimed in claim 12, wherein the organic binder is present in the liquid carrier in an amount of from 0.5 to 6 w/v%, preferably from 0.5 to 4 w/v%.
- 10 14. A method as claimed in any one of the preceding claims, wherein the ceramic slip comprises from 10 to 95 w/v% ceramic particulate.
- 15 15. A method as claimed in claim 14, wherein the ceramic slip comprises from 20 to 90 w/v% ceramic particulate, preferably from 40 to 80 w/v% ceramic particulate.
- 20 16. A method as claimed in any one of the preceding claims, wherein the ceramic slip further comprises one or both of a dispersant and/or a defloculant.
- 25 17. A method as claimed in any one of the preceding claims, wherein prior to burn-out of the organic binder the liquid carrier is allowed to evaporate from the foamed ceramic slip.
- 30 18. A method as claimed in claim 17, wherein the foamed ceramic slip is heated at a temperature in the range of from 20 to 100°C to facilitate evaporation of the liquid carrier prior to burn-out of the organic binder.
19. A method as claimed in claim 17 or claim 18,

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wherein the concentration of the organic binder in the liquid carrier is selected such that the percentage of binder remaining after substantially all of the liquid carrier has been evaporated is from 0.5 to 10 w/w%.

5

20. A method as claimed in claim 19, wherein the concentration of the organic binder in the liquid carrier is selected such that the percentage of binder remaining after substantially all of the liquid carrier has been evaporated is in the range of from 1 to 6 w/w%, preferably from 1 to 4 w/w%.

10

21. A method as claimed in any one of the preceding claims, wherein the foamed ceramic slip is cast in a mould having a surface coated with a release agent.

15

22. A method as claimed in any one of the preceding claims, wherein burn-out of the organic binder is carried out at a temperature in the range of from 150 to 700°C.

20

23. A method as claimed in any one of the preceding claims, further comprising sintering the ceramic foam following burn-out of the organic binder.

25

24. A method as claimed in claim 23, wherein sintering is carried out at a temperature in the range of from 500 to 1600°C.

30

25. A method as claimed in claim 23 or claim 24, wherein the sintered ceramic foam has a bulk porosity in the range of from 40 to 95%, preferably from 70 to 90%.

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26. A method as claimed in any one of claims 23 to 25, wherein the sintered ceramic foam has a strut density in the range of from 60 to 95%, preferably from 70 to 90% of the theoretical density of the ceramic.
27. A method as claimed in any one of claims 23 to 26, wherein the sintered ceramic foam has a modal pore size in the range of from 100 to 2000 μm , preferably from 100 to 1000 μm .
28. A macroporous ceramic foam obtainable by a method according to any one of the preceding claims.
29. A synthetic bone material which comprises a macroporous ceramic foam as claimed in claim 28.
30. A composition which comprises a macroporous ceramic foam as claimed in claim 28 or a synthetic bone material as claimed in claim 29 together with a pharmaceutically acceptable diluent or carrier.
31. A bone implant, filler, cement, tissue engineering scaffold, synthetic bone graft or drug-delivery device which comprises a macroporous ceramic foam as claimed in claim 28, a synthetic bone material as claimed in claim 29 or a composition as claimed in claim 30.

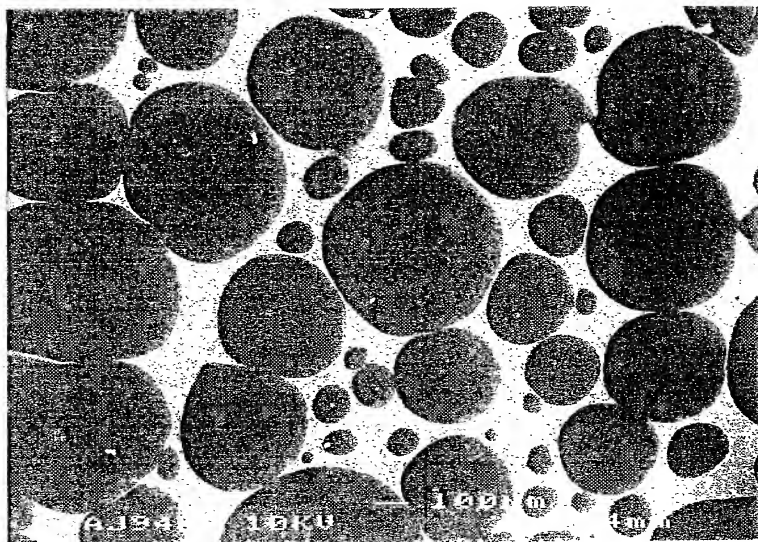


Figure 1 (Ref:TAJ942).

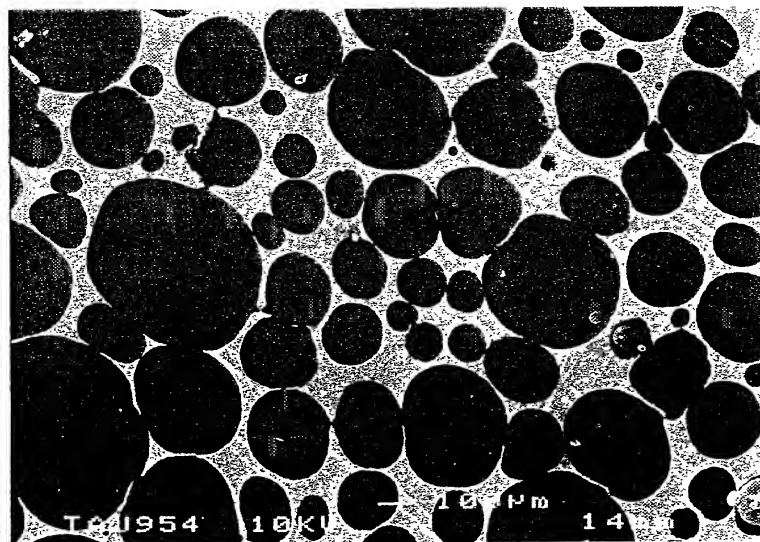


Figure 2 (Ref:TAJ954).

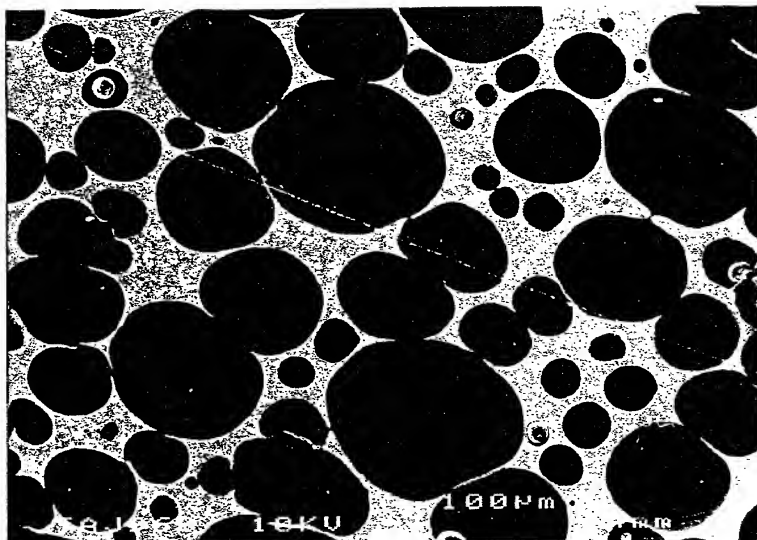


Figure 3 (Ref:TAJ960).

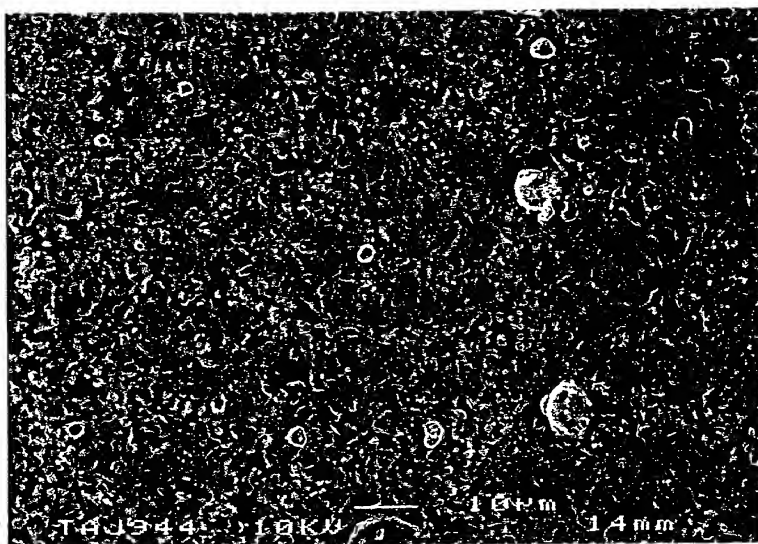


Figure 4 (Ref:TAJ944).

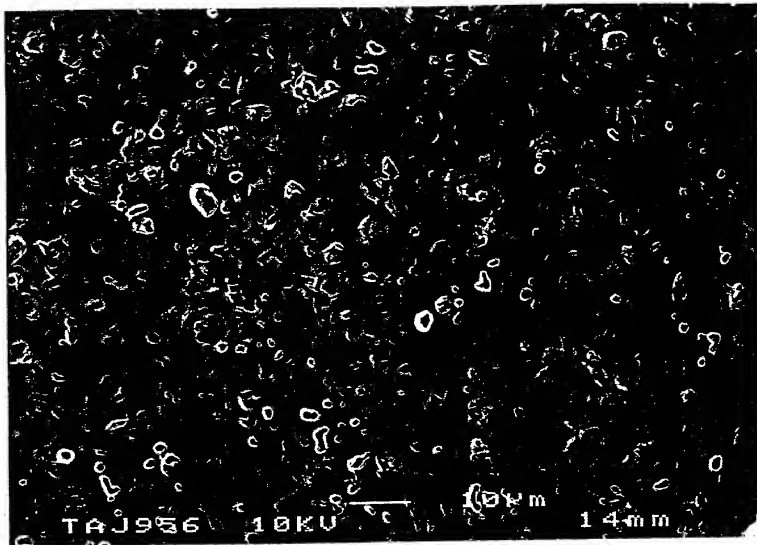


Figure 5 (Ref:TAJ956).

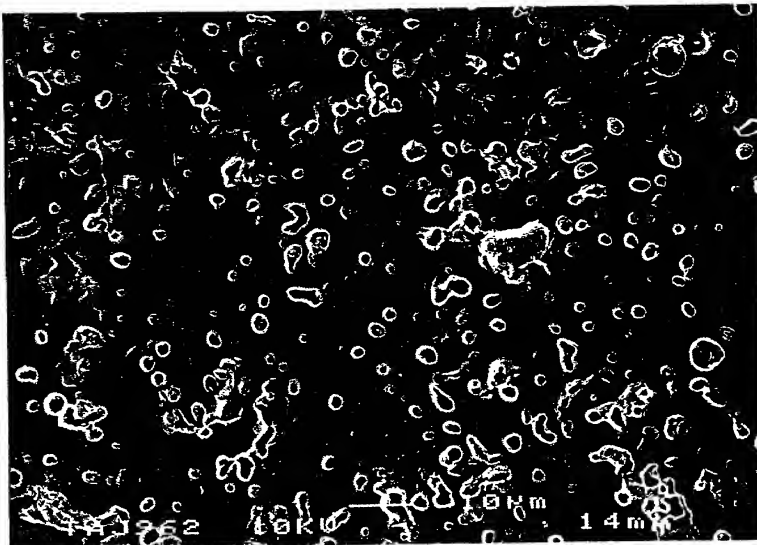


Figure 6 (Ref:TAJ962).

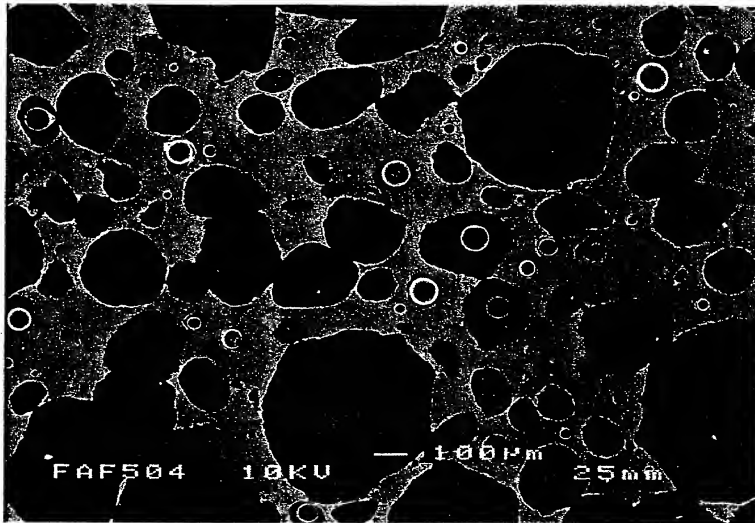


Figure 7 (Ref:FAF504).

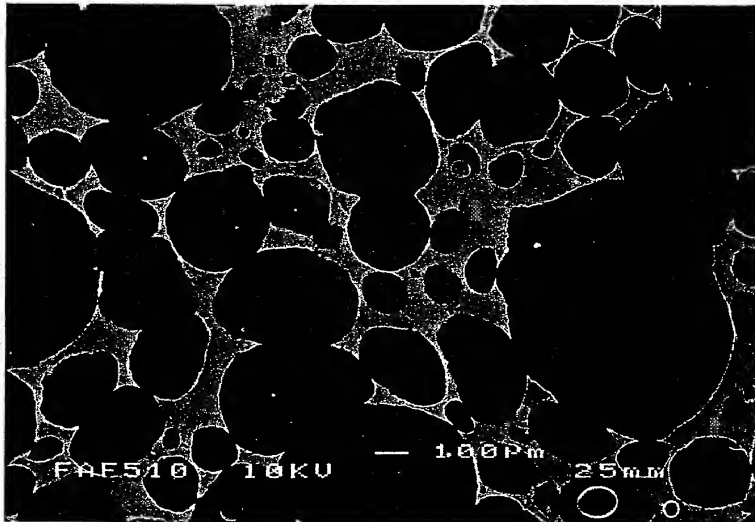


Figure 8 (Ref:FAF510).

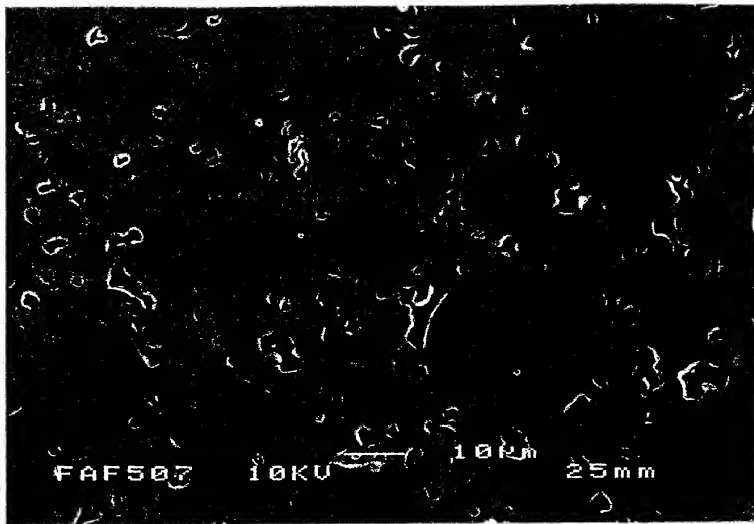


Figure 9 (Ref:FAF507).

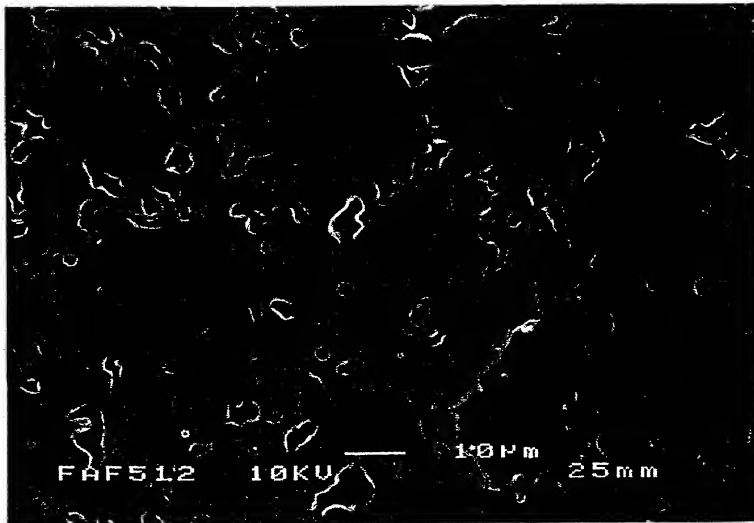


Figure 10 (Ref:FAF512).

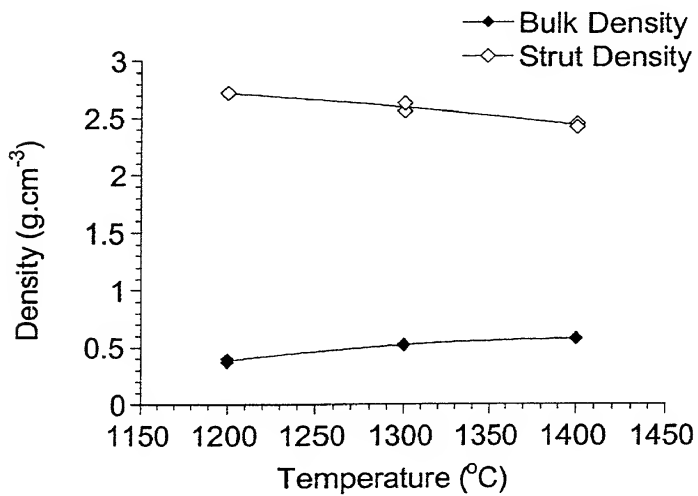


Figure 11

DECLARATION FOR PATENT APPLICATION AND APPOINTMENT OF ATTORNEY

As a below named inventor, I hereby declare that my residence, post office address and citizenship are as stated below next to my name; I believe that I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention (Design, if applicable) entitled:

the specification of which (check one):

☐ is attached hereto, or ☒ was filed on: 5 October 1999 as U.S. Application Number or PCT International Application

Number: PCT/GB99/03283

and (if applicable) was amended on:

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment(s) referred to above. I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, §1.56. I hereby claim foreign priority benefits under Title 35, United States Code §119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed.

PRIOR FOREIGN APPLICATION(S)			PRIORITY CLAIMED	
Number	Country	Day/Month/Year Filed	Yes	No
9821663.3	United Kingdom (GB)	5 October 1998	X	

☐ Additional Priority Application(s) Listed on Following Page(s)

I HEREBY CLAIM THE BENEFIT UNDER TITLE 35 U.S. CODE §119(E) OF ANY U.S. PROVISIONAL APPLICATIONS LISTED BELOW.	
Application Number	Day/Month/Year Filed

☐ Additional Provisional Application(s) Listed on Following Page(s)

☐ I hereby claim the benefit under Title 35, United States Code, §120 of any United States application(s) or PCT international application(s) designating The United States of America listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in that those prior application(s) in the manner provided by the first paragraph of Title 35, United States Code, §112, I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, §1.56 which became available between the filing date of the prior application(s) and the national or PCT international filing date of this application:

Application Number	Filing Date	Status - Patented, Pending or Abandoned

☐ Additional US/PCT Priority Application(s) listed on Following Page(s)

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

POWER OF ATTORNEY: I (We) hereby appoint as my (our) attorneys, with full powers of substitution and revocation, to prosecute this application and transact all business in the Patent and Trademark Office connected therewith: J. Ernest Kenney, Reg. No. 19,179; Eugene Mar, Reg. No. 25,893; Richard E. Fichter, Reg. No. 26,382; Charles R. Wolfe, Jr., Reg. No. 28,680; Thomas J. Moore, Reg. No. 28,974; Bruce H. Troxell, Reg. No. 26,592; Joseph DeBenedictis, Reg. No. 28,502; Benjamin E. Urcia, Reg. No. 33,805; and

I (we) authorize my(our) attorneys to accept and follow instructions from regarding any matter related to the preparation, examination, grant and maintenance of this application, any continuation, continuation-in-part or divisional based thereon, and any patent resulting therefrom, until I (we) or my(our) assigns withdraw this authorization in writing.

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DATE 23/5/01	SIGNATURE <i>[Signature]</i>

See following page(s) for additional joint inventors.


CONTINUATION OF DECLARATION FOR PATENT APPLICATION AND APPOINTMENT OF ATTORNEY

Page 2

PRIOR FOREIGN APPLICATION(S) (35 USC §119)			PRIORITY CLAIMED	
Number	Country	Day/Month/Year Filed	Yes	No

PRIOR PROVISIONAL APPLICATIONS 35 U.S. CODE §119(E)	
Application Number	Day/Month/Year Filed

PRIOR U.S. OR PCT INTERNATIONAL APPLICATIONS (35 U.S. CODE §120)		
Application Number	Filing Date	Status - Patented, Pending or Abandoned

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RESIDENCE ADDRESS <u>48 Harmer Green Lane</u> <u>Digswell, Welwyn</u> <u>Hertfordshire AL6 OAT. UNITED KINGDOM</u>	POST OFFICE ADDRESS IS THE SAME AS RESIDENCE ADDRESS UNLESS OTHERWISE SHOWN BELOW
DATE <u>4-June-01</u>	SIGNATURE 

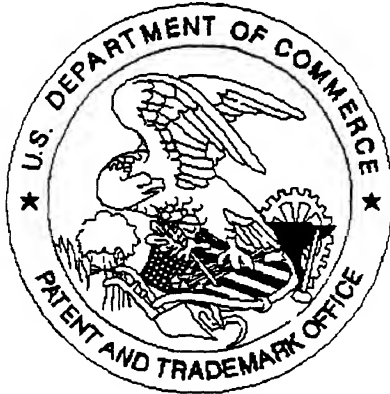
FULL NAME OF JOINT INVENTOR	CITIZENSHIP
RESIDENCE ADDRESS	POST OFFICE ADDRESS IS THE SAME AS RESIDENCE ADDRESS UNLESS OTHERWISE SHOWN BELOW
DATE	SIGNATURE

FULL NAME OF JOINT INVENTOR	CITIZENSHIP
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